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ABSTRACT — This paper, which was presented at the 64th annual meeting of the American Institute of Chemical Engineers November 29, 1971, examines the magnitude of loss of basic food grains due to inadequate, non-existent, or inefficient storage and distribution systems. The apparent shortage of nutritional commodities in a hungry world is called needless; and the significance of organized marketing in helping to reduce losses is emphasized.

Each year, as farmers harvest hundreds of millions of tons of grains, the challenge of production is followed by the enormous task of caring for, handling, and marketing these foods and feeds. In farm bins these grains are worth relatively little. When marketed through the proper channels they can earn billions of dollars for farmers and others, and can nourish the lives of people around the world. The individual steps involved and relative problems encountered in the movement of this grain to its ultimate destinations is examined in this report.

Obviously the main challenge is one of large volume bulk handling and storage and the related transportation to move these materials into channels of commerce. Transportation is a major cost element in domestic and world marketing of bulk commodities, and for many years the companies involved in this business have been improving methods for mass distribution. The growth and success of these companies appears directly related to progress in handling and transportation efficiencies.

In examining the world food problem, two major concepts deserve particular attention:

FIRST, the theory that there need not be a world food shortage. We have the acreage capacity and the know-how to generate the required feed stuffs. What the world lacks basically is a cash market — that is, consumers able to purchase these products and, equally important, an efficient low-cost distribution system to move the products from farm to consumer.

SECONDLY, grains must be considered perishable and must be handled as living substance — that is, they germinate, respire, are subject to mold and insect infestation, are confronted with both external and internal enzyme functions. They're contaminated with all the natural soil-sustained and air-borne micro-organisms, and of course are subject to breakage during handling.

The term bushel is actually a volume of dry measure. Different materials have different densities and packing factors.

The weight of a bushel of wheat as fixed by the Federal government is 60 pounds, barley 48 pounds, oats 32, rye 56, corn 56 pounds, and so on. Notwithstanding this archaic consternation factor, total grain production in the U.S. is approximately 10 billion bushels, and at an average of 50 pounds per bushel, the U.S. 1970 farm grain crop totaled approximately 500 billion pounds, a figure practically beyond comprehension of most people.

The following statistics will, hopefully, express the enormity of farm crop production. In spite of acreage restrictions, the 1970 United States production was estimated as follows:

Corn	**4.1 billion bushels**
Wheat	**1.4 billion bushels**
Soy beans	**1.2 billion bushels**
Oats	**1 billion bushels**
Sorghum	**700 million bushels**
Barley	**400 million bushels**
Flax seed	**30 million bushels**
Rye	**40 million bushels, or translated into**
FEED GRAINS	**160 million tons**
FOOD GRAINS	**46 million tons**

plus all the other minor grain and oilseed crops.

A few additional statistics:

It is estimated that crops are produced on approximately 3 billion of the earth's 33 billion acres, or almost 10 per cent.

It is further estimated that some of the countries having excellent conditions for production of grains, such as Canada and Australia, now cultivate only 3 to 4 per cent of their land areas.

It is also estimated that one third of the area planted to grain results in feed grade materials used to grow the milk and meat proteins necessary for world nutrition.

Grains are considered to represent approximately 70 per cent of the world's harvested acreage.

And a final statistic for the United States — export grain is and has been for quite a number of years the largest single favorable factor in this nation's balance of trade.

That briefly is the background for the tremendous challenge of protecting and moving the world's grain supply from its point of origin to its point of consumption be it flour miller, feed manufacturer, corn syrup maker or oil seed crusher. One paramount relationship to keep in mind is that everyone wants to make a fair

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profit. The farmer wants a fair return for his invested labor and risk, the grain elevator wants a satisfactory return on investment, the grain handler needs to evaluate all alternative methods of handling and transportation in order to keep the final cost to the food processor low enough so that the general population can afford his products. It therefore becomes mandatory that transportation innovation be looked at in every conceivable way to reduce the cost of handling to an absolute minimum.

A further complicating factor is the short harvest period and the huge inventories that must be handled in short time.

Let's consider a few of the tasks involved in storing grain in terminal elevators. The merchandiser must have an intimate knowledge of the grades of grain in his elevator and he must always be watching for ways to blend different lots of grain to upgrade the quality. In this blending process, account must be taken for the weight, moisture, and the ratio of damaged kernels all of which require rapid, accurate, sophisticated analytical methods. As you may well imagine, some grain comes in fairly clean, other grain with significant quantities of sticks, stones, stalk, chaff, and dirt. Since an elevator does not have the capacity to keep all grades segregated, the operator must make momentary decisions on whether to segregate or combine material from several origins. In the elevator, grain is frequently conditioned. This process can take many forms, but drying is probably the most common. The purpose of this is to conserve grain which may arrive with excess moisture and, if stored under high moisture conditions, would naturally respire, get moldy, generate heat and lose both protein and carbohydrate quality. The drying process is one of time, temperature, and humidity conditions; and there is always a temptation to run dryers at excessive temperatures, causing heat damage and shattering of brittle grain. A terminal operator also conditions grain by various other processes; for example, clipping — to raise the test weight by removal of small chaffed materials; bleaching — to improve the color; cleaning — to remove undesirable material; and by washing or scouring — to remove fungus, pesticide residue, large quantities of soil, and so on.

The grain harvest moves through an elaborate network of buying offices and elevators. It moves by truck, train, barge and ship. In each of these operations the grain is dumped and elevated, subjecting the individual kernels to damage. Constantly faster handling, to increase loading efficiency, causes greater physical impact and potential damage to the grain. Bucket elevators move faster, conveyor belts run faster, grain is thrown centrifugally harder off the end of turning conveyor belts, screw augers are moved at faster rates. Doing this while maintaining good dust pollution controls is an even greater challenge.

Yet another factor should be kept in mind: that grain is harvested during a very short period of time, unlike the continuous production of other large volume materials such as coal or petroleum. Yet consumers want grain products every day of the year and it would be grossly unfair to the farmer to limit his price opportunity to only that one day of the year when he brings his truckload of grain from the fields to the elevator. Further, it would be entirely unrealistic to expect a housewife to pay a price for bread that is based on widely fluctuating daily supplies of wheat or wheat flour. Much of this cyclic phenomenon can be smoothed out by using both the cash and the futures markets and in the sophisticated hedging methods used by all large grain companies to guarantee relative price stability.

The transportation network is multi-faceted. A truck brings grain to the elevator. Other trucks or rail cars move it from a small elevator to a network of inland elevators where it awaits loading on barge or additional rail units. So the grain is handled again, and subjected to physical forces that tend to cause breakage. Some inland elevators will load entire trains consisting only of grain-hauling-cars similar to the unit trains that have been used in the coal and iron ore industry. As grains are moving in every conceivable direction on every conceivable rail, barge, or truck line throughout the country, computers help link the customer with the supply, often directing changes in destination while the grain is in transit. Annually, a shortage of rail cars is experienced during the peak of the harvest season and the elevator operator frequently is forced to store some grain on the ground until sufficient cartage is available.

A significant portion reaching the interior elevators is loaded onto barges or rail for the trip to terminal or export eleavtors.

Since the largest balance of trade factor in the U.S. economy is the export of grain, one of the most keenly competitive segments of the grain industry operates at this stage. During the last 10 years there have been at least a dozen new export elevators on the Gulf Coast, several on the West Coast and several in the Great Lakes Ports. These new units, capable of storage of up to 15 million bushels at any single moment, are the most automated grain export terminals imaginable. They're operated through central panel boards with electronic controls which can regulate and combine the flow of grain from any storage bin. Grain is sold on a contract calling for specified grade, color, moisture and foreign material levels. Ideally, a contract calling for 12 per cent maximum moisture corn should be loaded into that boat at 11.99 per cent moisture if the elevator is operated in its most efficient manner. At the same time, if the maximum amount of non-grain foreign material, for example dust, twigs, stones, and other grains, is to be no more than 2 per cent, the objective would be to load at 1.99 per cent foreign material. It goes without saying that no silo in any elevator complex has exactly 11.99 moisture and 1.99 foreign material grain. The only way to achieve this kind of loading is to combine grains of similar grades from a number of the silo bins. All of this, of course, should be handled in the most efficient, least labor-intensive method possible. As a sideline to the export business, one must realize that international trade agreements, U.S. Governmental trade restrictions, fluctuating currencies, the cost of ocean freight and insurance (which fluctuate daily), interest on the financing of the grain which must be owned by someone during transit, and the success or failure of an overseas crop, all contribute to the complex picture for international export trade. It is no wonder that an extreme network of alert management, rapid international communications, and international lines of commodity credit and bank credit must be maintained. Not the least of all these factors is the changing political scene within various countries where grain can be either purchased or sold. Recall, for instance, what happened in 1967 when Russia decided to sell sunflower oil in the world cash market.

Yields of grain have been improved constantly through the ages. At first, farmers simply held back the better producing crops to be used for seeds in subsequent years. Introduction of hybrid genetics greatly increased the capability to produce, and the concurrent use of fertilizer, pesticides, crop rotation and other agronomic knowledge combine to give us the capacity to grow today's large crops.

Still the scientists are not satisfied. Hybrid genetics work in most fields continues at an aggressive rate. Almost each year sees release of new corn hybrids or soybean and wheat varieties. Within a few years the first release of some hybrid wheat and also sunflower can be expected. On a worldwide basis, the Borlaug contributions to wheat genetics are well known, and the progress made by the International Rice Research Institute in the Philippines signals significant break-throughs in higher yields. Through the years, farm output also has been vastly increased through mechanization, fertilizer and other chemicals, larger farming units and better managements. And this knowledge can be stretched and applied even more.

Let's turn back now to some of the other problems involved in grain handling and storage. Any discussion along these lines should begin with the repetitive reminder that the grain kernel is a living organism. It is a seed primarily for producing another plant.

The germ contains all chemical nutrients required for seedling growth such as sugar, carbohydrate, protein, vitamins, minerals and most of the oil present in that grain. But as the grain embryo begins to sprout, it draws on the kernel's reserves of starch, protein, and oil for nourishment. It is these same reserves that make grain valuable to man. Sprout prevention obviously is most important to the grain handler.

Quality in grain is reason enough to segregate poor, moderate, and good quality material. Good quality corn, for example, has fully matured kernels with a tight intact hull and a normal white or yellow color. Grain should be free of chips, mold damage, heat damage, insect cuts, unnatural chemical or animal contamination. There should be no sour, musty, or unnatural odors. The presence of any of these undesirable characteristics reduces the quality and therefore the usefulness of the grain as well as its price.

Many things can happen to degrade quality between the time grain is growing in the farmer's field and its utilization. For example, inadequate soil fertility, smut, leaf blight, delayed maturing, early killing frost — each of which can cause low test weight which equates to low yields of starch, unfilled kernels, excessive shattering, and so on. In almost any corn field, ears can be found that have become infected with cob rotting mold. Much of this damage has occurred before the grain is actually put in the hands of the handling company.

It is not unusual, either, to expect that high moisture grains would be easily subject to mold growth. Many years experience has told us that grain storage is relatively easy when the moisture is controlled in the range of 12 to 15 per cent. The optimum level will vary from one grain to another, but growth of micro-organisms requires moderate temperature and reasonable moisture.

Much of the field harvest will come in between 20 and 30 per cent moisture, a level too high for long term storage. By proper drying to the 10 to 14 per cent range, grain can be stored almost indefinitely.

A new trend in corn harvesting is field shelling, the use of the picker sheller or a grain combine equipped with a harvesting head. In either case, less field loss is encountered when the corn is harvested bewteen 20 and 25 per cent moisture. Above 25, the softer condition of the kernel results in more cracking, cutting, and bruising . . . and therefore a greater percentage of broken corn. These broken and crushed kernels permit easy entry and establishment of mold spores, leading to subsequent problems.

High moisture corn held in bulk for more than a few hours will start to heat, and darkened corn from spontaneous heating in bulk is undesirable for any food manufacturing or feed use. Germ and endosperm both are embrittled and protein cannot be separated from starch in wet milling. Moist grain on top of the loads exposed to air may begin to sprout while other portions may become severely moldy, sour or fermented.

Dryer damage can result if higher temperatures or long exposure to high temperatures is permitted. Therefore caution must be exercised by the processor to achieve reasonable dryer through-put yet maintain moderate dryer temperatures.

The exceedingly diverse microflora gives exposure to a myriad of enzyme systems that can contribute to deterioration. Moldy corn in any amount is of course undesirable in any food or feed product. Nutritive value is decreased and recent research has shown that some mold produced substances are toxic to animals. An example is the family of aflatoxins sometimes produced by *aspergilis flavus*. Moldy corn gives low oil yield in the wet milling process. Some molds that grow in the germ utilize the oil, thus causing the corn germ to be fragile on milling. Poor separation of starch from gluten may result from other types of moldy corn. Similar problems exist for all the other grains.

We know how to control certain molds by the addition of chemical materials. But can't you imagine the consternation of the many grain users (whether wet or dry millers or food or feed manufacturers) to a general chemical additive for mold control. How much simpler it is to control the moisture level and the temperature of the grain during storage.

We have therefore devised methods to quickly measure the temperatures of grain and to install temperature thermocouple cables in large storage bins so that the temperature of the grain pile can be taken easily. If the temperature beings to increase, that grain must be aerated to cool, or it must be separated or what we call turned over, moved from bin to bin causing a separation of that area where temperature rise is noted.

Rapid methods for the analysis of moisture are necessary. Conventional moisture analysis by oven techniques may take up to two hours, and therefore electrical capacitance methods have been devised which give an almost instantaneous reading. Likewise, it is necessary to find very rapid methods for detecting foreign material; and nearly all of these to date require a separation of whole kernel from extraneous material. Efforts are being made now to use optical reflectance and other newer techniques to determine the percentage of non-grain or broken grain materials in a grain sample.

But even after the drying is carefully conducted, the grain may not be sufficiently protected unless it is also inspected periodically during storage. Poorly constructed structures may allow entry of rats, mice and birds, which will contaminate the grain and make it unfit for food use. Inadequate inspection and absence of a fumigation schedule may allow insects to become established. Kernels may be eaten, and eggs and larvae may be deposited inside kernels. Insect activity will produce heating and promote mold damage, and insect fragment contamination will cause food inspectors to seize and destroy manufactured food products so contaminated. You can well understand that the use of residue-leaving insecticides and pesticides is undergoing close scrutiny today.

There is no ignoring the concept that grain must be handled properly to prevent or minimize the many possible deteriorations and the extreme potential loss in value during transit from farm to ultimate user.

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